Ad hoc networking using Wi-Fi during natural disasters: overview and improvements.

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ABSTRACT
This paper is about the use of ad hoc networking on people’s smartphones to send messages in a situation where help is needed and the infrastructure used to communicate cannot be used. The paper focusses on Wi-Fi because it has longer range than most of the other technologies. The method used will be literature studies to find out how to create an ad hoc network on a smartphone and what the advantages and disadvantages are. The practical part shows how to create a Wi-Fi ad hoc network program and at last there will be an performance evaluation of part of that program. The evaluation shows that both the length of the message and the distance to a receiver are of influence to the amount of messages that can be sent per second.

Keywords
Opportunistic networking, ad hoc network, smartphone, natural disaster, Wi-Fi.

1. INTRODUCTION
This paper is about ad hoc networking during natural disasters. Natural disasters happen a lot around us, not only in “third world” countries but also in the rest of the world. One of the problems after a natural disaster is finding the people who need help. Nowadays if someone needs help from the emergency services they will call them. After a natural disaster the communication infrastructure can be damaged. This will hinder the communication between the victim and the emergency services. One of the ways to reach the emergency services without the use of communication infrastructure is the use of ad hoc networking. Ad hoc networking uses multiple nodes to relay messages to other users of the network (Picture 1)

This is useful in case of a natural disaster and when there are enough nodes (people with smartphones) around to relay messages to the emergency services.

The benefit of using mobile phones is that a lot of people use smartphones. These smartphones have a couple of wireless communication technologies like Wi-Fi and Bluetooth. The use of these devices ensures that in (densely) populated areas a network to communicate can always be created.

The use of ad hoc networking during natural disasters has already been researched. Weiquan Lu et al. did research about communication support for disaster recovery [4]; this research had the communication between emergency services in mind. It could be a good addition to enable the communication between the service and the victims of the natural disasters. Also there are no current Wi-Fi based ad hoc networking programs for smartphones with the focus on getting messages to emergency services. The use of this type of ad hoc networking could improve the communication between the victim and emergency services.

Figure 1. Example of a message route through an ad hoc network

Firstly a literary study is done to find the advantages and disadvantages of Wi-Fi. Secondly a way to create a Wi-Fi ad hoc network is explained and last tests of this ad hoc network are done to determine if these advantages are useful.

2. PROBLEM STATEMENT
There are different technologies used to create ad hoc networks. Wi-Fi is one of them; this research will be about Wi-Fi because it has the longest range of the wireless technologies [3]. Range is essential because not only the highest density of victims (the ones that are within a close range of each other) but also the less high density of victims (those who are further away from each other) must be able to communicate with the emergency services.

It is interesting to know if and how a smartphone can create an ad hoc network, what the advantages and disadvantages are to the alternatives and how smartphone Wi-Fi ad hoc networking can be improved.

3. RESEARCH QUESTIONS
Following the introduction and problem statement these research questions can be identified:

- What are the advantages and disadvantages of ad hoc networking using Wi-Fi on smartphones as...
compared to the other technologies such as Bluetooth, UWB and ZigBee?

- How can Wi-Fi on smartphones be used to create an ad hoc network during a natural disaster?
- Evaluation of the advantages offered by ad hoc networking using Wi-Fi on smartphones.

4. ADVANTAGES & DISADVANTAGES

Wi-Fi is one of the many wireless technologies. Jin-Shyan Lee et al [3] identified four different wireless standards. These four are Bluetooth, UWB, ZigBee and Wi-Fi. These four wireless standards can be used to communicate between devices. Ondrej Hyncica et al identified three candidates for wireless communication: Wi-Fi, Bluetooth and ZigBee [2]. These four wireless technologies are compared in the next part in terms of: range, throughput, power consumption, availability on smartphones and number of nodes (the maximum amount of nodes in one ad hoc network).

4.1 Range

Range is an important requirement because the larger the range the greater the amount of people you can reach in lesser populated areas.

Jin-Shyan et al. wrote about a comparison of wireless standards [3]. One of the main advantages of Wi-Fi versus other technologies is range. Wi-Fi has a nominal range of about 100 meters where Bluetooth and UWB only have a range of 10 meters. Some implementations of ZigBee can also reach about 100 meters. The same ranges are in the evaluation of Ondrej Hyncica [2].

4.2 Number of Nodes

Number of nodes is important if you want to create a network that can cover a lot of ground and connect a lot of people. Combined with the range of a technology you can calculate how much ground you theoretical can cover and how much people can be reached.

Jin-Shyan et al.[3] states in their evaluation that the maximum amount of nodes is 2007, but also states that in an ad hoc implementation the number of nodes could be unlimited.

4.3 Throughput

Throughput is also important but not as important as range of number of nodes. This element shows how much information each node can receive from the network. However it does not mean the node can also send this amount of information over the network. This is the theoretical maximum throughput of the protocol.

Both Jin-Shyan et al. [3] and Ondrej Hyncica et al [2] gave the same number as the protocol implied. Wi-Fi has a maximum of 54 Mb/s, Bluetooth 1 Mb/s, UWB 110 Mb/s and ZigBee 250 Kb/s. UWB has the highest amount of throughput followed by Wi-Fi, far behind are Bluetooth and ZigBee.

4.4 Power consumption

Power consumption is in this case an important aspect. You want the victims of the natural disaster to be saved as quickly as possible but also that the network stays online for as long as possible, this to give the emergency services the longest time to find the people sending the messages. Power consumption is an indication of how long a network can exists while only using the smartphone’s battery.

Both Jin-Shyan et al. [3] and Ondrej Hyncica [2] gave the power consumption of the wireless standards. Ondrej Hyncica gave the power consumption in mA for using the antenna of the transmitter. This is an indication of how much power each protocol uses and thus how long each protocol could be running on a smartphone before draining the entire battery.

4.5 Availability on smartphones

The availability on smartphones of the technologies is the most essential. A technology can be the most efficient of them all but when it is not available on smartphones then it is useless in this type of situation. This requirement is a make or break condition: without it the wireless technology is not applicable to this situation.

The manufacture’s sites of current smartphones show that the current line of smartphones only has Wi-Fi and Bluetooth widely available [1, 5, 6].

4.6 Conclusion

Table 1 shows the overview of the advantages and disadvantages of the Wireless technologies.

<table>
<thead>
<tr>
<th>Table 1. Overview of advantages/disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
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<tr>
<td>-------</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Throughput</td>
</tr>
<tr>
<td>Power consumption</td>
</tr>
<tr>
<td>Number of nodes</td>
</tr>
<tr>
<td>Available on smart-phones</td>
</tr>
</tbody>
</table>

*Depends on the implementation of the technology.

Only Bluetooth and Wi-Fi are available on current smartphones. These two technologies are Bluetooth and Wi-Fi. The other two: ZigBee and UWB are not available and thus not useful for making an ad hoc network on smartphones. From the two available on smartphones Wi-Fi has the advantage of greater range, throughput, availability and the number of nodes, but at the cost of significant higher power consumption.

If ZigBee was available on smartphones it would be a great candidate to create an ad hoc network because with a good implementation the range would be the same as Wi-Fi but at a far less power consumption. But the throughput could be a problem in big networks where a couple of smartphones are the bottleneck for the entire network.
5. WI-FI AD HOC NETWORKING

5.1 Goal

The goal of the application is to create a possibility for victims of natural disasters to communicate with the emergency services. The technology used is Wi-Fi. This way the network can reach more people with fewer devices. The application should be able to work without any infrastructure; it has to be able to create an ad hoc network and send messages over this network.

5.2 Requirements

The application has to communicate with other devices via Wi-Fi. One of the ways to create an ad hoc network and which is currently supported by android is Wi-Fi Direct. This framework uses Wi-Fi to establish a connection between devices without needing to create a separate hotspot for each device.

When the devices are connected a simple client / server construction is used to send messages over the network. Each smartphone has a server where other smartphones can connect to. This way each smartphone acts as a node where other devices can connect to. Also every smartphone has a collection of sockets to other devices. Every time this smartphone sends a message it will be sent to all the devices it is connected to. Also every message received will be sent over the same sockets. This way a message from another device is transmitted over the network.

One of the ways the messages can be send through the network is flooding: every device broadcasts the messages received. One of the problems can be that a device that sends a message will receive the message back from the devices connected. This way a loop is created: one message will be broadcast over and over. One of the ways to fix this is to give an id to every message. This way a device must look up the id in a list from id’s send. This will prevent that the network keeps on broadcasting one message. Some way to prevent the constant looping of the messages over the network must be used in the application.

5.3 Existing solutions

One way to address the problem is making each smartphone a hotspot to which other smartphones could connect. The problem with this solution is that most smartphones cannot connect to multiple Wi-Fi hotspots.

Another existing way to create an ad hoc network on smartphones is to use Bluetooth. Only the scope of this research is to focus only on Wi-Fi. It could however be interesting to find out how exactly an ad hoc network was made using Bluetooth. This could contribute to create one of Wi-Fi faster.

5.4 Design

The next part of the paper describes the way the developed proof of concept application works. The application uses four steps: initialization, connection and communication.

The first step of the application is initialization: Create the User Interface with place to type messages and places to display the messages send. A server for incoming connections is created. This is the place where new connections from other devices are handled.

The second step is: Turn Wi-Fi and Wi-Fi direct on. Let every smartphone look for peer to connect to. When a peer has been found, the smartphone tries to connect to the other smartphone using Wi-Fi Direct. When the connection is successful one of the two devices is made group leader; the one who controls this connection (Figure 3). Each square (tube) between the nodes represents a Wi-Fi Direct Connection.

The third step is: The group leaders’ IP-address can be found by the other. The other device creates a new socket which connects to the server of the group leaders’ device. Now a connection has been made between the two devices. And the client/server of the chat has been connected. The users of the smartphones can now send messages to each other (Figure 4). Each grey line in the tube represents a connection of the chat service.

Figure 2. Initial state, each circle is a node; the range of the middle node is displayed.

Figure 3. State of the network after each device connects with peers within range.
Figure 4. State when the chat service of the devices connects to each other.
If one of the two initial devices finds another device the same will happen for those two (Figure 5). Every messages that one device receives will be send to all connected devices; this includes the one created by this devices. This was an ad hoc network is created and messages can now be send by the use of all these devices (nodes).

Figure 5. A new device is found and added to the network.
The third step is for the user to type a message in the User Interface and press the key to send this message. The program listens to this key press and sends the message to all the connected devices. Something like a panic or emergency button can be added to the application to ask easily for help.

6. EVALUATION
The next part of the paper evaluates these advantages (range and throughput). Due to material constraints the number of nodes (possibly unlimited) could not be evaluated.
The range test is done twice: First time the goal is testing the different factors in unobstructed space. These tests are done without walls blocking the signal. The second time the goal is testing the factors when there are obstructions, this will evaluate how a Wi-Fi ad hoc network will behave when there is debris blocking the signal.

6.1 Range
Range is an important factor. It determines the amount of other devices one can find. A couple of effects of range are tested: ability to detect (yes / no). This is a direct indicator of the range of Wi-Fi (100 meters) can actually be reached.
The second factor that is tested is the amount of messages per second a smartphone can send over a distance. This is an indicator of how much influence the range of the devices has on the messages per second of these devices. For example if the devices are 100m away and the number of messages goes to less than 1 message per second. This node is less useful, because it cannot relay a large number of messages to other nodes within the network.

Figure 6. Test setup, the first is without any obstacles, the second with obstacles between the phone and access point.
The tests are done by trying to connect to a server running on a laptop using Wi-Fi (See figure 6). This will show if a smartphone is able to connect to another Wi-Fi device over the distance. This done for the following distances: 10, 25, 50, 75, 100, 125 meters. The first distance (10 meter) is to establish a baseline of the amount of messages that can be sent when the phone is in a small proximity to the connected device. The other distances are to measure the performance on even greater distances, in theory Wi-Fi should be able to reach 100m. The 125 meter is to try if the device can connect to another beyond the theoretical maximum distance.
The unobstructed space tests are taken place somewhere where you can keep visual contact to the receiver. The obstructed space tests are taken place indoors and the larger distance tests are done when there are obstructions like buildings in between the smartphone and the receiver (Figure 6: the left is without any obstructions, the right with obstructions). If the buildings are (partly) blocking the signal, a difference in number of messages can be seen.
The messages sent are 10 characters long and 5000 messages are sent. The average number of messages per second is displayed in Table 2.
As seen in table 2, there are no results for the distances 50 meters and higher. The measurements for these distances could not be executed because the phone failed to detect and sometimes failed to connect to the receiver at these distances. This shows that the phone is not able to connect to devices that are farther away than 50 meters. And in the obstructed test the phone could not send the messages far beyond 25 meters this is different than what we might expect from seeing the protocol’s maximum range of 100 meters.

Table 2 shows that the distance to the receiver has an effect on the number of messages that can be sent. The number of messages per second range from 5,200 messages for a distance of 10 meters to about 3,800 messages for a distance of 25 meters. One of the explanations of the drop of messages per second could be that the Wi-Fi antenna takes longer to send a message over a greater distance. The longer it takes to send one message the longer it will take to send them all.

The obstructed tests show that the average number of messages for a distance of 10 meters is lower than unobstructed tests. And the numbers continue to drop, even though the amount per second does not go below 2,000 before not being able to connect to the receiver and not sending enough messages to measure over this distance.

### 6.2 Size of message

The size of the messages send could be of influence to the throughput of messages. Due to the way the messages are sent. If this payload can contain a 1,000, and if it was as fast as sending only 10 characters then the actual size of the messages are of no influence.

The number of messages that can be sent per second has been tested on a smartphone, using a client/server construction. The same setup as Figure 6 was used; the distance of the phone to the receiver was < 10 meters and no obstacles were in between the access point and laptop. The smartphone was then sending a large number of messages (5,000 and 10,000) and a testing program was keeping track of the time it took to send them all. The number of messages 5,000 and 10,000 is needed to eliminate for a part the time that the application is busy but not yet sending any messages over the number of messages. For example if the test will always take at least 1ms the time to send 1 messages will be far greater than the average time it takes to send 2 packets; the actual time to send 1 and the time it takes to start it up and print the results. Ten tests per amount of messages and amount of characters were done. The average amount of messages per seconds is shown at the results. Table 3 shows that the number of messages that can be sent from a smartphone depends a lot on the amount of characters per message. This means that the number of messages is very dependent on the size of the messages.

### 6.3 Speed (Mb/s)

Speed is another factor of the performance of the network. The speed could also be a factor to the number of messages that can be sent from a smartphone. These tests are to establish if the smartphone can possibly reach the theoretical maximum speed of Wi-Fi.

The transfer speed was tested using a speed test application called “Speed Test” for the smartphone. The smartphone used the Wi-Fi connection to test the throughput in Mb/s of the Wi-Fi. The results of the tests are in the table below.

Table 4. Results of up/download speed test.

<table>
<thead>
<tr>
<th>Distance (meters)</th>
<th>Characters/Number of messages</th>
<th>10</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6.400 / s</td>
<td>4.500 / s</td>
<td>2.400 / s</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

These test show that the length of each message correlates to the number of messages that can be send each second. This is to be expected; the longer the message the more data the Wi-Fi antenna must transmit and the longer it will take to transmit the data.

### Table 4. Results of up/download speed test.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Test up</th>
<th>Test down</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7.5 Mb/s</td>
<td>2.5 Mb/s</td>
</tr>
<tr>
<td>125</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>150</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>200</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>250</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>300</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>350</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
<tr>
<td>400</td>
<td>0 Mb/s</td>
<td>0 Mb/s</td>
</tr>
</tbody>
</table>

Table 4 shows that the Up and Download speed is significantly lower than the Theoretical maximum of the Wi-Fi technology. One of the explanations is that a smartphone has a smaller Wi-Fi antenna than for example a laptop. The technology does not guarantee the maximum speed. It depends on the antenna used.

Lessons learned from this test is that the even if the maximum speeds is about 54mb/s, in reality the speed can be significant smaller, even to the point that another technology like Bluetooth could even be faster; if using Wi-Fi gives a speed of about 100 kb/s Bluetooth could be able to outperform Wi-Fi.

### 7. DISCUSSION

#### 7.1 Advantages & Disadvantages

Some of the numbers found are theoretical numbers, like the maximum speeds of the protocol. This speed can only be reached under the most optimal circumstances. Also these numbers are not tested on smartphones. This means that the numbers might never be reached on a smartphone due to the limitations of the dimensions and technologies included.

The four technologies analyzed were Bluetooth, ZigBee, UWB and Wi-Fi. Some other protocols could be evaluated; for example a new version of Bluetooth: Bluetooth 4.0. This may as well be a better alternative to Wi-Fi than this version of Bluetooth. Other Wireless protocols which are even better than those tested can as well be developed in the future.

Another aspect of the protocols is how their signal strength is influenced by obstacles; this may be a very interesting factor for the main situation of the paper; natural disasters. However no research about signal strength and obstacles could be found. This aspect is partly tested in the evaluation of Wi-Fi.
7.2 Wi-Fi Ad hoc networking

It is possible to create an ad hoc network on a smartphone using Wi-Fi. But there are some limitations. The framework used is Wi-Fi Direct; this framework is capable of “one to many” type of connecting devices. When using “one to many” and those many connect to other devices also an ad hoc network is created. However some devices cannot handle “one to many” but can only manage to connect to one device at a time. The devices which can only connect to one other can be only be used in the network to send messages. Because every other message coming to the device is already known to the device it is connected to; the message is from the device itself or from another node in the network, the only connection to the network is the connected device. There can be another problem with these “one to one” devices; they can block the entire network. If a device is capable of around 10 connections at a certain time, and all these connections are taken by “one to one” devices then no ad hoc network can be created.

As described the application uses a flooding technique of sending messages through the network. Another way of sending messages is using efficient power aware routing algorithms [7] or using a reputation system for transmitting messages through an ad hoc network [8].

Text messaging could also be replaced by something else; when a network is created one could send whatever he or she wants; voice over IP or sending pictures and files is also possible. However this could slow the network down a lot; one sentence spoken in voice over IP could as well be lots of text messages send, the throughput of the network might not even be good enough to facilitate voice of IP software; this could be good question for other research.

One of the other uses of this program is to find victims and ask them where they are. This will require someone with a device within 25 meters to where the victim is located. If the victim is able to respond where he or she is the emergency services can find him or her faster.

Another use can be in a whole different situation; you can use the program to create a local network to send messages; for example broadcasting messages at a festival to the visitors of this festival.

7.3 Tests

Calculating the amount of messages per second of the smartphone relies on a bottleneck principle; one can only measure the slowest part in the network. The smartphone is considered the bottleneck. This is because the network on which it was tested has a very high throughput. Some measurements get far over the 54 Mb/s of maximum speed of Wi-Fi. Therefore it is likely that the measured throughput of messages was that of the smartphone. However there remains a small possibility that the bottleneck was somewhere else. For example the receiving device was currently doing something else or the network itself was a problem. The same can be said about the Speed measurement.

The main situation of this paper focusses on a natural disaster situation. This situation is quite hard to simulate; the way it is tested in this research is to try to connect from behind a wall (or a couple of walls) or behind a building for measurements far away. It is not certain that this way of testing correctly correlates to a real natural disaster situation. To find this correlation other research has to be done.

The effect of range on the amount of messages could be investigated further. If a message must be send over a larger range the Wi-Fi antenna could use more energy than when a message is send over a relative shorter distance.

The effect of obstacles between two connected devices and the number of message they can send could also be investigated further by trying out different materials. For example just concrete or stone obstacles or different kind of metals that are blocking the signals. This could explain the decline of messages / seconds by obstructed signals better.

The obstructed tests show that Wi-Fi is not able to connect well through obstacles. The maximum range found with obstacles was about 25 meters. This would mean that the smartphones of the victims need another node close by to relay the message through the network. The victims themselves who are further away than 25 meters could not connect to each other.

8. CONCLUSION

Overall it is possible to create a Wi-Fi ad hoc network on a smartphone. However there are some limitations; the phone must have Wi-Fi capabilities and must be able to connect to multiple devices at once.

The advantages of using Wi-Fi as compared to the other technologies are:
- Larger range (100 meters instead of 10)
- Higher throughputs than Bluetooth and ZigBee.
- Available on smartphones.

The major disadvantage is:
- Higher power consumption than Bluetooth and ZigBee.

On the whole Wi-Fi is the best choice on smartphones if you want a large range and a high throughput.

Creating an ad hoc network on a smartphone is also possible; one of the ways it could be done is using Wi-Fi direct. The limitation of this way of using Wi-Fi is that some devices are only capable of one-to-one connection to devices, and at least a part of the network must be capable of one-to-many connections to devices.

The throughput, power consumption and range of the network have been evaluated. The number of messages per second is highly correlated with the size of the messages.

The research shows that a smartphone is not able to establish a connection with another device over a range of 100 meters. The maximum range of where a smartphone could connect unobstructed was about 50 meters. The Maximum range with an obstructed path was even less; about 25 meters. Even though the effective range is less than 100 meters it is still better than for example Bluetooth; Bluetooth has a range of about 10 meters.

9. REFERENCES


